Logistics Management Institute

Lean Logistics and Its Impact on the USAF Spares Requirement

AF603RD1

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August 1996

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Prepared pursuant to Department of Defense Contract DASW01-95-C-0019. The views expressed here are those of the Logistics Management Institute at the time of issue but not necessarily those of the Department of Defense.

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INTRODUCTION

Declining funding and a continuing desire to improve logistics support have led the United States Air Force to launch the Lean Logistics program. Lean Logistics is a loosely linked set of initiatives aimed at improving processes in the management of aircraft reparable spare parts. It is chiefly aimed at increasing responsiveness by shortening the flow times for serviceable and unserviceable components through the supply and maintenance system.

Lean Logistics has significant potential for improving aircraft readiness and controlling support costs, and we present some estimates of potential cost reductions here. But the program has also caused some confusion in the Air Force logistics community, with some claiming that Lean Logistics necessitates that the Air Force develop new methods for setting required spares levels. In fact, as we will demonstrate, the Air Force requirements computation, when combined with complementing arrangements for establishing base requisitioning objectives and depot serviceable inventory goals, is already flexible enough to accommodate Lean Logistics. Even more than unnecessary, some of the proposed new level-setting methods are seriously deficient, particularly in the recognition of the multi-echelon nature of the supply system — the distribution of stocks of spares at geographically separated operating locations as well as at a central supply point, usually an air logistics center. Replacing current methods with the new proposals would actually result in degraded performance and fail to realize the full potential of Lean Logistics.

BACKGROUND

The Air Force maintains over $30 billion in inventory of reparable spare parts to support its fleet of 7,000 aircraft. These are the expensive aircraft components, like brake assemblies, avionics, or engine fuel controls, that are removed from the aircraft when they fail. Ideally, one has a serviceable spare available to install in the aircraft so that it remains mission capable while the failed component is repaired, either by base maintenance or by an off-site activity.

Because of this large investment (and the continuing expense to repair failed components and procure new spares to support new weapon systems, modifications to existing weapon systems, changes to component failure patterns, and the like), the Air Force devotes a great deal of management attention to this area.

Over the years, the Air Force has developed and implemented sophisticated probabilistic models to deal with the inherent uncertainty of the demand process and calculate spares mixes that provide desired support levels at minimum cost.

Recently, the Air Force has begun to focus on process improvements as an avenue to cost minimization. The Lean Logistics initiative is a loosely linked program of process improvements aimed at increasing logistics systems effectiveness, largely by improving responsiveness. Lean Logistics focuses more on quick response to parts shortages when they occur rather than on attempting to preclude shortages by investment in large inventories. The Air Force effort is paralleled by attempts to reduce logistics response time throughout the Department of Defense. The Army's Velocity Management concept and the Navy's Regional Maintenance concept have many elements in common with Lean Logistics.

Recent studies and Air Force demonstration projects have shown that dramatic reductions in response time are possible. These reductions can be achieved by exploiting the use of today's fast and inexpensive transportation and by fostering an attitude in the maintenance shops that prizes responsiveness and quick throughput, rather than the local efficiencies usually achieved by accumulating "batches" of failed carcasses for simultaneous induction and repair.

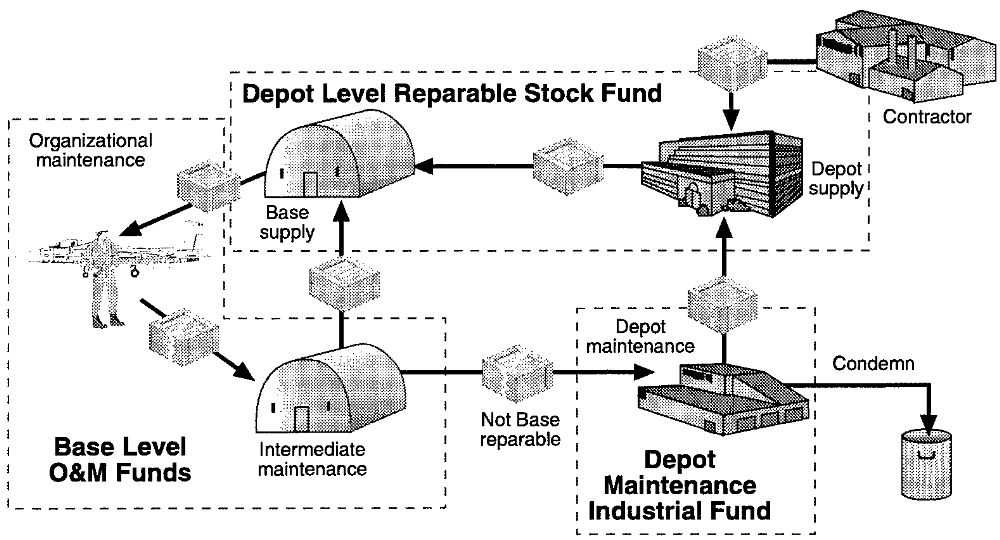
Some quarters of the Lean Logistics community believe that such responsiveness is so dramatic as to necessitate a completely new concept in requirements determination, a complete revamping and replacement of the statistical models now in place. In fact, the models are perfectly amenable to a Lean Logistics environment, needing only parameter changes to reflect the increased responsiveness of Lean Logistics. It is true that many of the existing automated systems are antiquated and overdue for an upgrade. Their lack of timeliness is an impediment to realizing the benefits of Lean Logistics and must be overcome. But there is no need to reinvent the last 30 years of inventory theory simply to accommodate the new responsiveness in maintenance and transportation.

We will first briefly outline Air Force logistics operations and the procedures used to set spares requirements and spares levels. We will then describe some key elements of Lean Logistics and give some quantitative estimates of the impact on required funding for spares that will come with the full implementation of Lean Logistics. Finally we will discuss the implications of Lean Logistics for Air Force requirements determination and demonstrate that the proposed framework emerging from the Lean Logistics community already has perfect analogies in the existing framework.

The Process

Like the other Services, the Air Force operates a multi-echelon supply system. Spares are stocked at "retail" or first-echelon sites — the operating bases — and also centrally at the "wholesale" echelon or depot. Retail stocks provide immediate support for individual base-level activities, while wholesale stocks provide protection for all the operating locations, although with a delay for processing and transportation to the retail site.

Figure 1 depicts the maintenance and resupply process at a typical Air Force operating base. An aircraft failure is isolated to a failed component, which is removed from the aircraft by organizational — or squadron — maintenance. The failed carcass is repaired by base intermediate maintenance and returned to base supply. If the carcass is not base reparable, it is returned to the depot — one of the air logistics centers — for repair at the more extensive industrial facilities there. (In some cases, a commercial contractor fills this role.)



Note: O&M = operations and maintenance.

Figure 1.
Rotating Logistics Flow

Multi-Echelon Maintenance and Supply Operations

In concert with these maintenance activities, the supply system is reacting as well. The failed component is replaced by a serviceable unit from base supply if one is available; if not, the aircraft is NMCS (not mission capable — supply) until a serviceable unit is produced by base maintenance or received from depot stocks. If the carcass is shipped to the depot for repair, the base simultaneously generates a requisition for a serviceable unit from depot supply. The unit is shipped immediately, if possible; otherwise the next available one produced from depot maintenance is shipped.

Although not central to our discussion, the existence of financial entities designed to facilitate financial management and create incentives in the process should be noted. The Depot-Level Reparable (DLR) Stock Fund "sells" serviceable spares to maintenance activities, and the Depot Maintenance Industrial Fund "sells" repaired components to the DLR Stock Fund. Our simplified treatment here glosses over the issue of supplying repair parts and subassemblies to assist repair, as well as such other depot maintenance operations as airframe overhaul, although these activities are significant sources of spares demand and are included in the requirements computation. In other words, we deal only with the support to organizational and intermediate maintenance and with components that are (flight) line replaceable units (LRUs) — removed from aircraft upon failure and directly affecting aircraft readiness.

Calculating Expected Backorders

As a first step in calculating spares requirements, we need to be able to calculate the performance provided by a given spares level. For performance measures, the Air Force uses expected backorders (EBOs) at base level — i.e., the expected number of unfilled demands — and the relationship of those EBOs to aircraft availability.

Let's look first at a single base and suppose that the base has a spares level s. The basic inventory relationship is

$$s = OH + DI, \qquad \text{[Eq. 1]}$$

where OH represents stock on hand and DI represents stock due in, either from base maintenance or from depot supply.

We interpret a backorder (a spare owed to an aircraft) as negative on-hand stock. If no items are due in, the level will be on the shelf as serviceable on-hand spares. Usually, however, some spares are due in, moving through resupply; thus on-hand stock is less than the level. Spares are fluid, in a sense, making a transition from unserviceable to serviceable on hand, to installed on aircraft, to unserviceable again, and so on. The levels and Equation 1 are the mathematical description of this flow.

Note that a demand on supply, which drops the level to $s-1$, is followed immediately by initiation of a resupply action to bring the level back up to s. In inventory theory terms, the base operates an $(s-1, s)$ inventory system. (For inexpensive high-demand consumable items, bases operate an economic order quantity [EOQ] system, ordering in quantity when stock on hand drops below a predetermined reorder point.) Expressing this basic equation as $OH = s-DI$, we can see that the relationship of the spares level to the due-in quantity determines whether there are serviceable spares in stock, or whether there are backorders and unfilled aircraft demands. So we now look in detail at this random variable: the number of items in the resupply pipeline.

Suppose demands are generated at a single base by a Poisson process with distribution function $p(x{:}\lambda)$ where λ is the daily demand rate.[1] This process splits binomially into a base-reparable Poisson process with mean λ_B and a depot-reparable Poisson process with mean λ_D, where $\lambda_B + \lambda_D = \lambda$. If *BRT* is the mean base repair time, applying Little's Formula shows that the mean number of units in the base repair pipeline is $\lambda_B \bullet BRT$. If *OST* is the order and ship time to receive a spare from the depot, and if the depot always has a serviceable spare to ship, then the mean number of demands due in from the depot is the order and ship pipeline = $\lambda_D \bullet OST$. We can go a step further here and apply Palm's Theorem,[2,3] originally derived in the 1930s in the analysis of telephone switching networks, to characterize the probability distribution of these pipeline segments. Palm's Theorem states that when the demand process is Poisson with mean *m*, and the resupply times are independent and identically distributed with mean *T*, then the steady-state distribution of the number of units in the resupply queue is Poisson with mean *mT*. A surprising fact here is that the distribution of resupply times does not affect the steady-state distribution of the number in resupply.

Using Palm's Theorem, we can characterize the base supply pipeline as Poisson-distributed with mean $\mu_B = \lambda_B \bullet BRT + \lambda_D \bullet OST$.

From this we can use the standard formulation to calculate expected backorders with a spares level *s*

$$\begin{aligned} EBO &= E_x\ [(x-s)\,;\, x \geq s] \\ &= \sum_{x \geq s} (x-s)\,p\,(x;\,\mu_B), \end{aligned} \qquad \text{[Eq. 2]}$$

where $p\,(x;\,\mu_B)$ is the Poisson probability of *x* demands with mean μ_B.

But we have assumed here that the depot always has stock. A true multi-echelon treatment must explicitly consider the stock level at the depot and the possibility that some resupply from the depot is delayed and takes longer than OST to reach the base. Applying the EBO formula to the depot, let *DRT* be the depot repair time, λ_o the depot daily demand ($\lambda_o = \Sigma\, \lambda_D$ *summed over all the bases*), and s_D the depot stock level. Then the number of expected depot backorders, EBO_D, is given by

$$EBO_D\,(s_D) = \sum_{x \geq s_D} (x - s_D)\,p(x;\,\lambda_o \bullet DRT). \qquad \text{[Eq. 3]}$$

[1] As a matter of fact, we observe more variability in demand than can be explained by a Poisson process. The Air Force actually uses a negative binomial distribution for demand, which can be thought of as arising from a Poisson process with an unknown mean, itself characterized by a gamma distribution. The derivations here are applicable to the negative binomial as well.

[2] G. Hadley and T.M. Whitin, *Analysis of Inventory Systems*, Englewood Cliffs, N.J.: Prentice-Hall, 1963.

[3] Logistics Management Institute, *The Aircraft Availability Model: Conceptual Framework and Mathematics*, Report AF201, T.J. O'Malley, 1983.

Applying Little's Formula again, the average delay due to shortages of stock at the depot is given by

$$DD = \frac{EBO_D(s_D)}{\lambda_o} = \frac{EBO_D(s_D)}{\Sigma\,\lambda_D}. \qquad \text{[Eq. 4]}$$

So now, given a spares level s_D at the depot and spares levels s_B at each base, we can calculate the base resupply pipeline:

$$\begin{aligned} \mu_B &= \lambda_B \bullet BRT + \lambda_D\,(OST + DD) \\ &= \lambda_B \bullet BRT + \lambda_D \bullet OST + \frac{\lambda_D}{\Sigma\,\lambda_D} \bullet EBO_D\,(s_D). \end{aligned} \qquad \text{[Eq. 5]}$$

And for a spares level s at the base, we can calculate base expected backorders:

$$EBO\,(s) = \sum_{x>s} (x - s)\,p(x;\,\mu_B). \qquad \text{[Eq. 6]}$$

This allows us to determine, for given total stock, the optimal distribution between base and depot. We need only calculate the total number of base EBOs resulting from each possible distribution and choose the distribution that gives the smallest total EBO figure. Note that the tradeoff balances concentrating stock at bases — a procedure that can provide immediate response to a demand but ensures a lengthy delay when a demand is backordered from the depot — and concentrating stock at the depot — a procedure that reduces depot delay for *all* bases but does not contribute to immediate response at any individual base.[4]

Calculating Availability

Given a total spares level, $s(i)$ for a component i, we can now find the best distribution of that level between bases and the depot and calculate the corresponding worldwide base-level expected backorders, $EBO[i,\,s(i)]$. The Air Force requirements computation goes a step farther and estimates the effect of these backorders on aircraft availability — the probability that an aircraft is not missing a part. We consider a system of components i to be those applied to a particular aircraft type (e.g., the F-15 or the C-5) with a total of N aircraft. Suppose that all the components are line replaceable units, with a quantity of one per aircraft. Suppose further that failures are independent and that there is no cannibalization (i.e., backorders are scattered randomly across the fleet of aircraft). Then the aircraft availability rate — the probability that a random aircraft is not missing a part — is

$$A = \prod_i \left\{1 - \frac{EBO\,[i,\,s\,(i)]}{N}\right\}. \qquad \text{[Eq. 7]}$$

[4]For a more detailed discussion, see C.C. Sherbrooke, "METRIC: A Multi-Echelon Technique for Recoverable Item Control," *Operations Research*, 1968, pp. 122 – 141.

The requirements problem for this weapon system then is to maximize A, subject to a cost constraint. Marginal analysis is used to do this, but operating on

$$\ln A = \Sigma \ln \left\{1 - \frac{EBO\,[i, s\,(i)]}{N}\right\}. \qquad \text{[Eq. 8]}$$

Taking the logarithm makes the expression additively separable, and, obviously, maximizing the log will also maximize the availability. Since the individual terms are (approximately) convex, building a spares mix by choosing spares in the order of marginal benefit per cost ("bang per buck" in a classic military operations research phrase) can be shown to provide optimal inventories. Thus, if $c(i)$ is the procurement cost of component i, choosing spares in order of the largest

$$\frac{\ln \left\{1 - \frac{EBO\,[i, s\,(i) + 1]}{N}\right\} - \ln \left\{1 - \frac{EBO\,[i, s\,(i)]}{N}\right\}}{C_i}$$

develops a series of optimal (undominated) solutions for various levels of gradually increasing costs. The Aircraft Availability Model (AAM)[5] — developed by the Logistics Management Institute for the Air Force and now at the core of the requirements computation for peacetime operating stock — tracks these choices, and the resulting availability rates and costs, to produce curves of weapon system availability against cost (see Figure 2). These curves are used by Air Force logistics planners to determine the funding required to attain desired weapon system readiness and to analyze the consequences of various allocations of fixed budget funding. Once these fiscal decisions are made, the AAM is then used to guide actual item procurement actions.

[5] Logistics Management Institute, *The Aircraft Availability Model: Conceptual Framework and Mathematics*, Task AF201, T.J. O'Malley, 1983.

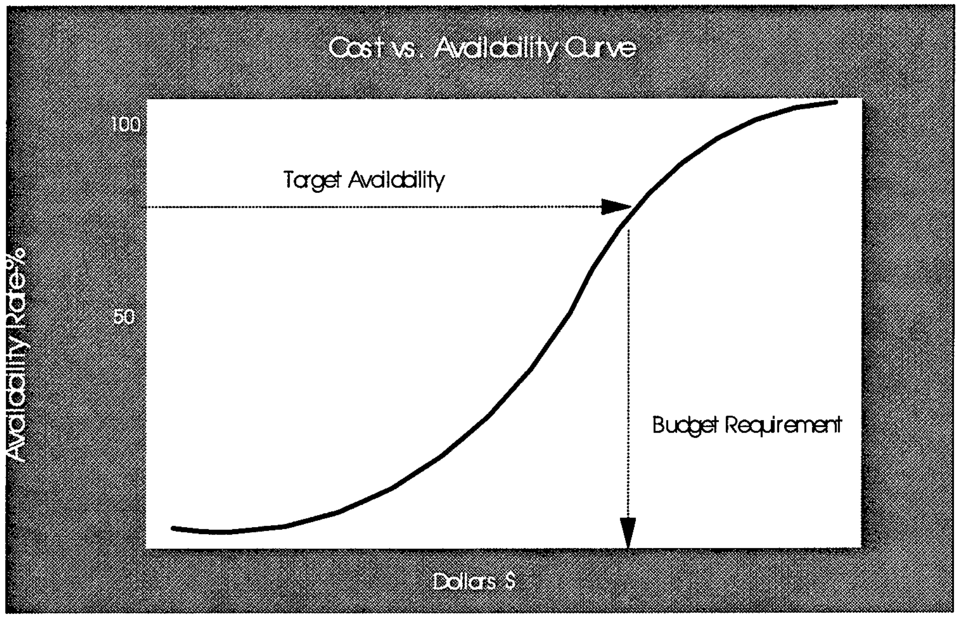


Figure 2.
Weapon System Approach (Marginal Analysis – Bang per Buck)

Summary of the Process

The preceding pages constitute, perforce, a very brief overview of the Air Force requirements determination process for aircraft reparable spares. Some of the issues we have not treated could, in fact, warrant lengthy discussion. We have not mentioned, for instance, how to treat cannibalization, or common components, or demand forecasting, or the effect of multiyear procurement leadtimes on budget formulation and requirements estimation. But we do hope we have outlined the basics well enough to inform our discussion of Lean Logistics in the next section.

Lean Logistics

In the discussion of requirements determination, we saw the crucial role that the component resupply pipeline plays. From the requirements perspective, of course, the goal is to ensure acceptable support at the least cost, given item and system characteristics. From the larger management perspective, however, one can also institute process improvements to reduce pipelines. All else being equal, smaller pipelines result in better support at lower cost. Reliability improvement programs, for example, shrink pipelines by reducing failure rates and hence the number of items that enter the pipeline. Lean Logistics addresses the other major dimension of pipeline size: the resupply time. The major principle of Lean Logistics is the reduction of transportation and repair times, a substitution of velocity of items through resupply for mass of inventory.

To reduce transportation times, for example, Lean Logistics envisions increased use of commercial rapid transportation as provided by carriers like Federal Express and Emory. While not suitable for classified, heavy, large, or otherwise "ugly" cargo, this approach is perfectly suited for avionics components, which constitute a large part of the spares flow. (Avionics components inventory is $19.2 billion or 55 percent of the total. Of the $6.08 billion in total dollar value of annual depot demand, avionics constitutes $3.51 billion or 58 percent.)

A major initiative is the introduction of a "repair on demand" discipline into the depot maintenance induction process. The concept is to establish a consolidated serviceable inventory (CSI) at the depot to be used as an induction trigger. When a demand is received from a base, it is filled from the CSI. The drop in CSI level causes an unserviceable unit to be inducted into repair. Thus, monitoring the status of the CSI suffices to guide induction decisions. In the inventory theory terms of the previous section, this is simply the introduction of a true (s–1, s) discipline into the maintenance process. It may seem strange that this introduction was necessary since the spares requirement models assume an (s–1, s) resupply system, but maintenance has long departed from such a system in practice.

Typically, depot maintenance has operated on a quarterly negotiation basis. Component demands and repairs are forecast quarterly. Maintenance and supply use these quantities (and any "catch-up" requirement to augment a deficient spares position) as the starting point for a negotiation, which allows for capacity, labor, or skills constraints; maintenance efficiencies; operational priorities; funding; and a host of other considerations. The negotiated quantity becomes the repair target for that quarter, and maintenance works to achieve that target. The target may well be adjusted as priorities change over time (and the Air Force is implementing a maintenance requirements system with a shorter planning horizon), but the quarterly negotiation is the prevailing process.

While this process may have been acceptable years ago when it evolved, it is no longer acceptable today. One drawback is that if quarterly demands are not as forecast (which happens more often than not, given the high variability of observed component demand), maintenance should adjust the target to reflect the change, but there is no systematic way to do this. Thus, if an item fails more often than expected during a quarter, working to the negotiated target fails to adjust to the need for more repairs. Similarly, an overestimate of demand leads to more repairs than needed. Additionally, the tendency to repair the quarterly target in a batch can result in serviceable assets being produced later in the quarter than needed. It can also distort the repair-time statistics collected and used in the requirements computation. In contrast, the (s–1, s) CSI discipline is self-adjusting.

While, for some components, batching for the sake of maintenance efficiencies may continue to be a valuable strategy (setup times may be so long that the "repair on demand" concept is unworkable), the Lean Logistics philosophy is to accept some inefficiencies in maintenance to attain the greater goal of responsiveness. In the case of avionics, there are few, if any, drawbacks to repairing on demand. Avionics components are typically repaired on automated test stands, where setup time is minimal, usually consisting only of loading the proper diagnostic software and attaching the component to the stand. Batching and/or working to a fixed quarterly target has little benefit in such a situation.

Some Potential Benefits of Lean Logistics

Clearly, implementing Lean Logistics will be difficult for the Air Force. But the potential benefits are great, both in terms of better support to aircraft readiness and in reductions in inventory and procurement expenditures. To see the magnitude of these potential reductions, we can use the AAM and item-level spares data to estimate funding requirements today and then to estimate what they would be if Lean Logistics resupply times were attained and used in the computation. Table 1 is a summary of current average times for various segments of the resupply pipeline compared with a set of unofficial, but reasonably attainable, "lean" times.

Table 1.
Average Pipeline Times

Pipeline segment	Current days	Lean Logistics days
Base repair	6	2
Order and ship (depot to base)	17	11
Retrograde (base to depot)	19	6
Depot repair processing (organic)	20	45% reduction
Depot repair processing (contractor)	73	30

Source: September 1994 D041.

All of the results in Table 1 and in the following paragraph were derived from the September 1994 Air Force reparable spares database, the D041 system. Both requirements and asset data in D041 are highly dynamic. While the results shown below illustrate the effects of flowtime reductions upon requirements, the precise impacts will, in fact, vary as force structure funding levels and item demand patterns change.

For the approximately 99,000 aircraft reparables managed by the Air Force, the value of the pipeline calculated by using current times is $2.7 billion. With the more responsive times, the pipeline is reduced to $1.2 billion, as shown in Table 2.

Table 2.
Pipeline Requirement
($ millions)

Pipeline segment	Dollar value of pipeline, using current times	Dollar value of pipeline, using fast times
Base repair	374	119
Order and ship (depot to base)	455	312
Retrograde (base to depot)	679	270
Depot repair processing (organic)	501	210
Depot repair processing (contractor)	678	263
Total	2,687	1,174

While a reduction of in-process inventory of $1.5 billion is dramatic and desirable, unfortunately not all of that reduction translates into savings. Many items already have stocks adequate to cover the larger pipelines (and, in fact, were bought to cover the even larger pipelines of the larger Air Force of several years ago). Reducing their pipelines does not avoid cash outlays since the items were not in a buy position anyway. In fact, AAM estimates shows savings of only $520 million in actual buy requirement (over a three-year period if the accelerated times were attained today). This is still a significant savings, but a far cry from $1.5 billion. Other savings will accrue over time as the shorter pipeline times reduce the need for spares when new components and new weapon systems are fielded.

An interesting point, also, is the extent to which the potential savings are concentrated in a few components. Today's $2.7 billion pipeline value is concentrated in about 20,000 components (NSNs or national stock numbers). Of the $520 million in procurement reductions over three years, $517 million is provided by just 1,000 NSNs. The top 100 alone constitute $345 million in reduction. This is an exceptional example of the Pareto principle, and it sends a strong message to the Air Force that implementation of Lean Logistics must capture these relatively few, high-payback NSNs.

Computing Lean Levels

The Air Force has struggled with the problem of how to set spares levels in a Lean Logistics environment, particularly with the issue of determining levels for the depot CSI. Analysts in Lean Logistics have proposed methods that have some merit but nonetheless fall short, particularly in treating the multi-echelon aspects of the supply process. This is not surprising, since Lean Logistics implementation is controlled largely by the maintenance community, which has little familiarity with the nuances of the supply system, nor the years of inventory theoretic research brought to bear on the problem.

But it is clear, even from basic principles, that stock levels at the base — where the aircraft are — must be considered in setting stock levels at the depot, which is actually what the CSI level is in requirements system terms. In fact, the requirements system now calculates a depot spares level that does balance stockage at base and depot to achieve maximum weapon system readiness. Currently, it uses longer resupply times than the Air Force hopes to achieve with implementation of Lean Logistics, but these are simply input parameters to the computation and easily adjusted.

The issue of data timeliness must also be addressed. The Air Force D041 system, which computes requirements, is an antiquated, 1960's-style batch processing system badly in need of updating. But the levels calculation itself is not faulty, and it would be a step backward to replace this calculation with a myopic one that did not view the system as a whole and obtain the best weapon system support possible.

To illustrate the impact of unwise level setting for the CSI, we can examine how expected backorders — at the most important location, base level — behave as depot stock changes. Some within the Lean Logistics community have developed proposals for setting CSI levels that consider only depot behavior and measures and are focused only on reducing depot backorders and increasing depot fill rates (the probability of having stock on hand when a demand is received). Thus, the fact that higher depot fill rates — more stock at the depot, better depot performance — do not automatically provide lower base backorders and aircraft availability is of critical importance.

Table 3 summarizes the results of various distributions of a fixed total stock between bases and the depot for a representative component. It assumes lean response times — a base repair time of 1 day, order and ship time of 3 days, and depot repair time (including retrograde time) of 6 days. The component is used at 25 bases, has a total Air Force inventory of 37 assets, a total daily base demand rate of 0.508, a daily depot demand rate of 0.423, and a resulting depot pipeline of 2.54. Column 1 of the table shows various depot levels, column 2 shows the corresponding depot supply availability or fill rate (the expected percentage of demands on the depot that are filled immediately), and column 3 shows the resulting average depot delay in days. Column 4 shows the most important performance measure, base expected backorders (EBOs), which determines this component's contribution to aircraft availability, as in Equation 7. A critical characteristic of this item, and a typical characteristic of a multi-echelon system, is that overall performance (i.e., base expected backorders) does not decrease monotonically with increasing depot levels. The lowest base EBO figure is achieved with a depot level of 4, though the curve is quite flat and a level of 5 does as well to three decimal places. After this point, base EBOs and NMCS aircraft increase as spares are siphoned away from the bases to the depot. A targeted depot fill rate of 90 percent or 92 percent, which is a typical proposed value, results in a depot level of 8. Although this fill rate may seem more "acceptable" than the 74 percent or 81 percent attained by the better levels, it results in an 8 percent increase in base EBOs.

Table 3.

Depot Levels and Base Expected Backorders (DRT = 6 Days)

Depot level	Depot fill rate (percent)	Depot delay (days)	Base EBOs
0	0.0	6.00	0.240
1	30.5	4.36	0.238
2	50.2	3.18	0.216
3	64.0	2.33	0.211
4	73.8	1.71	0.208
5	80.8	1.26	0.208
6	86.0	0.93	0.211
7	89.7	0.68	0.216
8	92.4	0.50	0.224
9	94.4	0.37	0.234
10	95.9	0.27	0.246
15	99.1	0.06	0.343
20	99.8	0.01	0.488
25	99.9	0.00	0.669
37	100.0	0.00	1.450

Note: 25 bases; base repair time = 1 day, order and ship time = 3 days, and depot repair time = 6 days; daily demand rate = 0.508, and depot DDR = 0.423; 37 spares.

The key to understanding this behavior lies in the depot delay column. Recall that depot delay is a key factor in determining the effect of depot stock on base EBOs. In this case, with no stock at the depot, the delay is 6 days. Each demand must wait a full depot repair time for the returned carcass to complete repair. The first spare added to the depot level has a dramatic effect on depot delay and a reasonable effect on base EBOs, which are determined largely by base stocks with their immediate response. Once there is a level of five spares at the depot, delay reductions from increasing the level are only small fractions of a day and do not offset the effect of reducing a base level. Furthermore, with 25 bases and 37 spares, depot stock greater than 12 forces some bases to have a level of zero. This causes the sharp rise in EBOs at the bottom of Table 3. For this component, in fact, understocking at the depot seems less serious than overstocking.

Note that a level of 4 spares at the depot would result in an average on-hand serviceable level of 1.46, since 2.54 are in the depot pipeline on average. But variability forces the depot to be out of stock about a quarter of the time, anyway, although assets already in repair emerge with an average delay of a little over a day and a half. This is "fast enough" to attain minimal base EBOs.

Table 4 presents a similar analysis, with a less stringent depot repair time of 20 days, but all other component characteristics unchanged. With the same number of assets but a longer pipeline, overall support suffers, of course, but the same pattern occurs as the depot level increases. In this case, the lowest EBO total occurs with a depot level of 8 (though neighboring values do almost as well). But notice the depot fill rate. In this spares-limited case, the lowest EBO of 2.055 is attained with a depot fill rate of 51 percent. Targeting, say, a 90 percent fill rate would give a depot level of 17 spares and an EBO total of 2.529, an increase of 23 percent in EBOs.

Table 4.

Depot Levels and Base Expected Backorders (DRT = 20 Days)

Depot level	Depot fill rate (percent)	Depot delay (days)	Base EBOs
0	0.000	20.00	2.544
1	0.019	17.68	2.450
2	0.060	15.46	2.354
3	0.120	13.38	2.268
4	0.192	11.47	2.184
5	0.272	9.76	2.131
6	0.354	8.23	2.087
7	0.435	6.89	2.062
8	0.511	5.74	2.055
9	0.581	4.75	2.064
10	0.645	3.91	2.084
11	0.701	3.21	2.113
12	0.750	2.62	2.154
13	0.793	2.13	2.211
14	0.829	1.72	2.275
15	0.859	1.39	2.354
16	0.885	1.12	2.439
17	0.906	0.90	2.529
18	0.924	0.72	2.655
19	0.939	0.57	2.787
20	0.951	0.46	2.943
21	0.960	0.36	3.102
22	0.968	0.29	3.263
23	0.975	0.23	3.436
24	0.980	0.18	3.618
25	0.984	0.14	3.804
30	0.995	0.04	4.945
35	0.999	0.01	6.784
37	0.999	0.01	7.880

Note: 25 bases; base repair time = 1 day, order and ship time = 3 days, and depot repair time = 20 days; daily demand rate = 0.508 and depot DDR = 0.423; 37 spares.

Table 5 shows an analysis for the case where there are 50 assets in the system — the component has the full requirement rather than a sparse spares inventory. We see the same pattern. The minimum EBO total of 0.971 is attained with a depot level of 9 and a depot fill rate of 58 percent. Leveling for a 90 percent depot fill rate results in a depot level of 17 spares, as before, and total base EBOs of 1.183, an increase of almost 22 percent.

Table 5.
Depot Levels and Base Expected Backorders (Given Additional Assets)

Depot level	Depot fill rate (percent)	Depot delay (days)	Base EBOs
0	0.000	20.00	1.179
1	0.019	17.68	1.136
2	0.060	15.46	1.100
3	0.120	13.38	1.072
4	0.192	11.47	1.046
5	0.272	9.76	1.021
6	0.354	8.23	1.001
7	0.435	6.89	0.986
8	0.511	5.74	0.975
9	0.581	4.75	0.971
10	0.645	3.91	0.975
11	0.701	3.21	0.984
12	0.750	2.62	1.000
13	0.793	2.13	1.023
14	0.829	1.72	1.053
15	0.859	1.39	1.089
16	0.885	1.12	1.130
17	0.906	0.90	1.183
18	0.924	0.72	1.248
19	0.939	0.57	1.314
20	0.951	0.46	1.382
21	0.960	0.36	1.462
22	0.968	0.29	1.546
23	0.975	0.23	1.634
24	0.980	0.18	1.726
25	0.984	0.14	1.820
30	0.995	0.04	2.387
40	1.000	0.00	4.177
50	1.000	0.00	7.877

Note: 25 bases; base repair time = 1 day, order and ship time = 3 days, depot repair time = 20 days; daily demand rate = 0.508, and depot DDR = 0.423; 50 spares.

Not every component will behave this way, or course. The optimal depot levels may result in a higher or lower depot fill rate or delay. But it is crucial not to look at the depot in a vacuum, but rather in the multi-echelon context. Measures of depot performance give an incomplete and possibly misleading picture. With fixed total assets, moving stock from base to depot improves response to a minimum of the order and ship time. While depot stock does provide a system-wide benefit, instead of a single-base benefit, and even through the ship-time penalty is small in a lean environment, it still makes sense to find the best mix. And since the techniques are well known and much of the machinery already in place, there is no need to settle for second best.

Analyses similar to those just described, conducted by the Air Force Logistics Management Agency (AFLMA) and by the Studies and Analysis Office at Air Force Materiel Command (AFMC/SAO), have led to the decision to compute stockage levels in a way that optimizes the system performance. The recommended approach, known as readiness-based leveling (RBL), has been approved for implementation.[6] The D041 system and RBL work in tandem. The D041 computes an aggregate worldwide level, but it has no access to the near-real-time data on aircraft basing and local demand patterns. It assumes that item demand is equally divided among using bases. RBL accepts the aggregate levels from the D041 and then refines the D041 "first cut" by using specific base-level parameters to allocate the requirements level. The two processes work together to develop a depot level to trigger repair inductions and base levels (requisitioning objectives) that are consistent with the inventory levels (buy requirement) and produce optimal weapon system support.

In this way, the D041–RBL combination is consistent (the sum of the RBL levels equals the D041 requirement) and optimizes the distribution of the requirement so as to maximize readiness. Moreover, RBL can be used to provide a target response time for each part to the supporting depot. The target reflects the retail-level stockage allocation as opposed to specifying arbitrary depot effectiveness goals that are not tied to system performance.

In summary, the existing D041 requirements system can support Lean Logistics principles. Rather than revamping the requirements system to achieve "simplicity," it would be better to focus attention on D041 inadequacies: principally, these are lack of timeliness and extensive reliance upon labor-intensive file maintenance. Given that these areas are addressed, and that careful attention is given to the details of RBL implementation, Lean Logistics principles can be successfully implemented without any wholesale "reengineering" of the requirements system.

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[6] S. Reynolds et al., *Setting Recoverable Item Stock Levels,* AFLMA Final Report L595995D0, January 1996.

REPORT DOCUMENTATION PAGE

Form Approved OPM No.0704-0188

1. AGENCY USE ONLY ***(Leave Blank)***

2. REPORT DATE
Aug 96

3. REPORT TYPE AND DATES COVERED
Final

Lean Logistics and Its Impact on the USAF Spares Requirement

5. FUNDING NUMBERS
C DASW01-95-C-0019
PE 0902198D

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER
LMI–AF603RD1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
HQ USAF/LG

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
none

12a. DISTRIBUTION/AVAILABILITY STATEMENT
A: Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

Declining funding and a continuing desire to improve logistics support have led the United States Air Force to launch the Lean Logistics program. Lean Logistics is a loosely linked set of initiatives aimed at improving processes in the management of aircraft reparable spare parts. It is chiefly aimed at increasing responsiveness by shortening the flow times for serviceable and unserviceable components through the supply and maintenance system.

Lean Logistics has significant potential for improving aircraft readiness and controlling support costs, and we present some estimates of potential cost reductions here. But the program has also caused some confusion in the Air Force logistics community, with some claiming that Lean Logistics necessitates that the Air Force develop new methods for setting required spares levels. We demonstrate that the Air Force requirements computation, when combined with complementing arrangements for establishing base requisitioning objectives and depot serviceable inventory goals, is already flexible enough to accommodate Lean Logistics. Some of the proposed new level-setting methods are seriously deficient, particularly in the recognition of the multi-echelon nature of the supply system — the distribution of stocks of spares at geographically separated operating locations as well as at a central supply point, usually an air logistics center. We describe an optimal multi-echelon method to set levels and realize the full potential of Lean Logistics.

14. SUBJECT TERMS
spares, stock levels, multi-echelon, lean logistics, aircraft availability

15. NUMBER OF PAGES
20

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298, (Rev. 2-89)
Prescribed by ANSI Std. 239-18
299-01